SECTION 16718

# VEHICLE TRAFFIC CONTROL SIGNAL HEADS – Light Emitting Diode (LED) Circular Signal Supplement

## PART 1 GENERAL

### 1.01 SECTION INCLUDES

The purpose of this specification is to provide the minimum performance requirements for a 300 mm (12 in) Light Emitting Diode (LED) vehicle traffic signal module while in service. This specification is not intended to impose restrictions upon specific designs and materials that conform to the purpose and the intent of this specification. This specification is not restricted to any specific LED technology.

### 1.02 DEFINITIONS

A. Catastrophic Failure: The total loss of visible illumination from an LED light source.

B. Chromaticity: The color of the light emitted by a module, specified by the *x*, *y* chromaticity coordinates on the 1931 Commission Internationale d'Eclairage (CIE) chromaticity diagram.

C. Conditioning: Energizing a LED signal module at a specified ambient temperature for a specified period of time, to cause any early electronic component mortality failures to occur and to detect any component reliability problems.

D. Duty Cycle: The amount of time during a specified time period that a module is energized, expressed as a percent of the specified time period.

E. Hard Coat: A surface coating or film to provide front surface abrasion resistance.

F. LED Light Source: A single light emitting diode (LED) or an array of LEDs.

G. LED Signal Module (module): A signaling unit comprised of an array of LEDs and related power supply, and any required lenses, which, when connected to appropriate power, provides a circular signal indication.

H. Luminance: The luminous flux emitted or reflected from a surface, in a given direction, per unit solid angle, divided by the area of the surface, expressed as $cd/m^2$.

I. Luminous Intensity: The luminous flux emitted in a given direction from a source, per unit solid angle, expressed in candelas (cd).

J. Minimum Maintained Luminous Intensity: The minimum luminous intensity a module is required to provide throughout service as a traffic control signal.

K. Nominal Operating Voltage: The AC RMS voltage, 120 VAC, at which photometric performance and power consumption are specified.

L. Power Consumption: The electrical power in Watts consumed by a module when operated at nominal operating voltage and ambient operating temperature range.

M. Power Factor: The power factor equals Watts divided by Volt-Ampere or the ratio of power consumption in Watts to Volt-Amperes.

N. Total Harmonic Distortion (THD): THD is the ratio of the root-mean-square (RMS) value of the harmonics to the amplitude of the fundamental component of the AC waveform.

O. Translate: To move an object along a linear vector, such that the orientation of the object does not rotate relative to the original frame of reference.

P. Turn OFF Time: The amount of time required after removal of the nominal operating voltage for the LED signal module to show no visible illumination.

Q. Turn OFF Voltage: The voltage below which the LED signal module emits no visible illumination.

R. Turn ON Time: The amount of time required for the LED signal module to reach 90% of full illumination.

S. Volt-Amperes: The product of the root-mean-square (RMS) line voltage and RMS line current, measured with true RMS meters.

T. Diffused: Lens must be designed to diffuse the light form the LED array over the surface of the lens.

1.03 ENVIRONMENTAL REQUIREMENTS

A. All exposed components of a module shall be suitable for prolonged exposure to the environment, without appreciable degradation that would interfere with function or appearance. As a minimum, selected materials shall be rated for service for a period of a minimum of 72 months in a south-facing Arizona Desert installation.

B. A module shall be rated for use throughout an ambient operating temperature range, measured at the exposed rear of the module, of -40°C (-40°F) to +74°C (+165°F).

C. A module shall be protected against dust and moisture intrusion, including rain and blowing rain.

D. The module lens shall not crack, craze or yellow due to solar UV irradiation typical for a south-facing Arizona Desert installation after a minimum of 72 months in service.

1.04 CHECKLIST

The checklist attached to the end of this specification shall be used as a tool by the City of Houston to insure compliance to the specification. On any discrepancies between the checklist and the body of the specification, the checklist shall govern. Substantiating documentation when required must be supplied from Independent Test Services Laboratory. This will ensure that all modules are measured on the same equipment, and reported in the same format.

A. WARRANTY AND GUARANTEES

1. All material, workmanship and labor furnished shall be covered by Supplier(s)/Manufacturer(s) guarantee and/or warranty for a minimum period of seventy-two (72) months. Warranty period shall begin the day the LED signal module is received by the City of Houston, either as new order or warranty repair. Bidder shall also be required to have resources to complete any required warranty work within fifteen (15) days after receipt of found defective LED signal module. The City of Houston's preference is for all non-warranty service to be charged a singular flat-rate. Successful bidder will include flat rate repair cost, if available in bid document for all non-warranty covered repairs. If flat rate repair charge is not available, then Supplier(s) Manufacturer(s) will provide current hourly labor rate, along with any associated minimum charges that may apply.

2. Successful bidder shall bear all expenses connected with return of any material which the City deems necessary to return for adjustments during guarantee period.

3. The City of Houston reserves the right to withhold payments which may be due, should it be discovered that material does not meet specifications and/or claims of bidder.

4. Supplier(s)/Manufacturer(s) shall make all engineering data, diagrams, software changes or improvements, which increases performance of equipment purchased under this bid, available to the City of Houston at no additional cost.

5. Supplier(s)/Manufacturer(s) shall have field engineers or technicians available on request to assure satisfactory initial operation, and to consult with City's Traffic

Engineer, or his representative, on any special circuitry that may be required in certain applications.

6. Each item furnished must have barcode data that can be used to reference project. Provide soft copy of barcode data for all items in data base format such as Access or Oracle. Provide all necessary equipment to electronically interpret/read individual barcodes, upload/download and process warranty information. One complete set of equipment shall be provided for every one-thousand units with a maximum of four sets total.

   Unit(s) to be sent to:

   Public Works and Engineering Department
   Traffic & Transportation Division
   Attention: Michael Wahl, P.E.
   Phone # (713) 881-3172

7. Must furnish for city independent testing of warranty one (1) Spectra Candella III Traffic Signal Test Kit ST-TSL-2000 Standard Kit or equal.

   Unit is to be sent to:

   Public Works and Engineering Department
   Traffic & Transportation Division
   Attention: Michael Wahl, P.E.
   Phone # (713) 881-3172

## 1.06 LIQUIDATED DAMAGES FOR LATE DELIVERY

A. Time is of the essence in this Contract and accordingly all time limits shall be strictly construed and rigidly enforced. The materials shall be furnished and fully delivered within the delivery time specified in the Bid Proposal and Purchase Order to be furnished to the Supplier(s)/Manufacturer(s)by the City. City and Supplier(s)/Manufacturer(s) agree that the City will suffer damages if the Supplier(s)/Manufacturer(s) fails to provide the material at the exact time and location specified by the City in accordance with this Contract and that the amount of damages will be difficult or impossible to determine. In order to provide a reasonable mechanism to compensate to the City for its damages, the Supplier(s)/Manufacturer(s) agrees to pay, or credit against any amounts due to the Supplier(s)/Manufacturer(s) from the City under this Contract one-half (1/2) of one (1) percent per day of the total dollar amount of late delivery items in the subject order for all days in excess of the specified number of days for delivery.

B. Computation of late delivery charges will commence the day following specified delivery date and will end the day of actual delivery less one (1) day. The number of these days times the dollar value of the items times 0.005 will equal the dollar value of liquidated damages to be deducted by the City from amounts owed to the Supplier(s)/Manufacturer(s).

1.07 SPECIAL NOTICES:

A. The City of Houston requests that the bidders shall furnish within thirty (30) days of notification of this contract from Material Management Division, two (2) LED signal modules. Sample shall be used for testing, evaluation of system and operational function, specification compliance. Failure to comply within fifteen (15) days of written request for suggested changes shall be just cause for rejection of bid from further bid award consideration. Sample testing, etc. will be completed as expeditiously as possible for return of the signal module to the firm(s), which submitted such signal module.

Sample is to be sent to:

Public Works and Engineering Department
Traffic & Transportation Division
Attention: Michael Wahl, P.E.
Phone # (713) 881-3172

PART 2 PRODUCTS

2.01 MATERIALS

A. LED SIGNAL MODULE

1. A module shall be capable of replacing the existing optical components or signal module in a signal housing, or shall provide a complete replacement of the signal head. Note all 200 mm (8 in.) signal heads will be changed to 300 mm (12in.)

2. The module lens shall be hard coated or otherwise made to comply with the material exposure and weathering effects requirements of the Society of Automotive Engineers (SAE) J576.

3. The module lens supplied shall be covered by transparent film or materials with similar color and transmissive characteristics.

4. The module lens may be a replaceable part, without the need to replace the complete LED signal module. Removal of lense will be with simple hand tools and such that no inclusion of additional adhesive, sealants, etc will be required to provide replacement of lense.

5. Materials used for the lens and module construction shall conform to ASTM specifications for the materials, where applicable.

6. Lens must diffuse the LED array over the entire surface of the lens.

7. LED Modules used for arrows must meet same photometric and chromaticity requirements as circular modules. (optional)

8. Enclosures containing either the power supply or electronic components of the signal module shall be made of UL94 flame retardant materials. The module lens is excluded from this requirement.

## 2.02 MODULE IDENTIFICATION

A. Each module shall be identified on the backside with the manufacturer's name, model, operating characteristics and serial number. The operating characteristics identified shall include the nominal operating voltage and stabilized power consumption, in watts and Volt-Amperes.

B. Modules and removable lenses shall have a prominent and permanent vertical indexing indicator, i.e., UP Arrow, or the word UP or TOP, for correct indexing and orientation in the signal housing.

C. Modules conforming to all non-optional requirements of this specification may have the following statement on an attached label: "Manufactured in Conformance with the COH LED Circular Signal Supplement."

## 2.03 PHOTOMETRIC REQUIREMENTS

A. Luminous Intensity, Uniformity & Distribution.

1. Minimum maintained luminous intensity: When operated under the conditions defined in Sections 1.03-B and 2.04-A-1, the luminous intensity values for modules shall not be less than the values calculated using the method described below for a minimum period of 72 months.

2. Calculate the vertical intensity factor ($f(I_{Vert})$) for the range from 12.5 degrees up (+12.5) to 27.5 degrees down (-27.5), using the appropriate equation:

For $\theta_{Vert} > -2.5$ degrees:

$$f(I_{Vert}) = 0.05 + 0.9434 * e^{-\left(\frac{\theta_{Vert}+2.5}{5.3}\right)}$$

For $\theta_{Vert} \leq -2.5$ degrees:

$$f(I_{Vert}) = 0.26 + \left(\frac{\theta_{Vert}}{143}\right) + 0.76 * \left[e^{-0.02(\theta_{Vert}+2.5)^2}\right]^{(-0.07*\theta_{Vert})}$$

where: $\theta_{Vert}$ is the angle measured above or below a horizontal plane perpendicular to the face of the module lens. (Note: angles above the horizontal plane are positive, while angles below the horizontal plane are negative.)

3. Calculate the horizontal intensity factor ($f(I_{Horiz})$) for the range from 27.5 degrees left to 27.5 degrees right:

$$f(I_{Horiz}) = 0.05 + \left(0.95 * e^{\left(-\frac{1}{2}*\left(\frac{\theta_{Horiz}}{11}\right)^2\right)}\right)$$

where: $\theta_{Horiz}$ is the angle measured from a vertical plane to the left or right, perpendicular to the face of the module lens.

4. Select the appropriate peak minimum maintained luminous intensity value for the specified module size and color:

Peak minimum maintained luminous intensity values, at $\theta_{Vert}$ = –2.5 deg and $\theta_{Horiz}$ = 0 deg [$I_{(-2.5, 0)}$], by size and color of the module are:

| Color | $I_{(-2.5, 0)}$ 200m | 300m |
|---|---|---|
| Red | 165 cd | 365 cd |
| Yellow | 410 cd | 910 cd |
| Green | 215 cd | 475 cd |

5. Multiply the vertical intensity factor times the horizontal intensity factor (for the selected pair of angles). Round the result to two significant figures, and multiply the combined angular intensity factor times the peak minimum maintained luminous intensity value for the appropriate signal size and color:

$$I_{(\theta vert,\ \theta horiz,\ size,\ color)} = [f(I_{Vert})^* f(I_{Horiz})]^* I_{(-2.5,\ 0)}$$

The resultant value of the luminous intensity shall be rounded to the nearest whole number.

Example: What is the minimum maintained luminous intensity value for a green, 300 mm LED signal light at 5 degrees down and 10 degrees left?

$$I_{(-5,\ 10,\ 300,\ Green)} = [f(I_{vert\ =\ -5})^* f(I_{horiz\ =\ 10})]^* 475\ cd$$
$$I_{(-5,\ 10,\ 300,\ Green)} = [0.953^* 0.678]^* 475\ cd$$
$$I_{(-5,\ 10,\ 300,\ Green)} = 0.65^* 475 = 309\ cd$$

6. Table 1 located at end of spec., provides the minimum maintained luminous intensity values, over the required angular range, at 5-degree increments. Note that the horizontal limitations vary for various vertical angles (e.g.: at $\theta_{Vert}$ = +12.5 degrees, requirements are only specified from 7.5 degrees right to 7.5 degrees left, while at $\theta_{Vert}$ = -12.5 degrees, the horizontal limitations are from 27.5 degrees right to 27.5 degrees left). Table 2 located at end of spec, provides the minimum maintained luminous intensity values, over the required angular range, at 2.5-degree increments. Tables 1 and 2 are provided to illustrate the minimum required values at certain specific angles within the required angular range of performance (i.e. while testing for light output compliance of a module in a

laboratory, an agency may use Table 1, and/or other specific pairs of vertical and horizontal angles of its choosing within the required angular range.) One must use the procedure outlined above for determining the minimum maintained luminous intensity values at any specific pairs of vertical and horizontal angles within the required angular range.

7. Maximum permissible luminous intensity: When operated within the temperature range specified in Section 1.03-B, the actual luminous intensity for a module shall not exceed three times the required peak value of the minimum maintained luminous intensity for the selected signal size, and color.

8. Luminance uniformity: The uniformity of the signal output across the entire module lens shall not exceed a ratio of 10 to 1 between the maximum and minimum luminance values ($cd/m^2$).

B. CHROMATICITY

1. Color regions: The measured chromaticity coordinates of modules shall conform to the following color regions, based on the 1931 CIE chromaticity diagram (see Figure 1):

Red: $y = 0.308$; $y = 0.953 - 0.947x$; $y = 0.290$:

| Point | Red | |
|---|---|---|
| | *X* | *y* |
| 1 | 0.692 | 0.308 |
| 2 | 0.681 | 0.308 |
| 3 | 0.700 | 0.290 |
| 4 | 0.710 | 0.290 |

Yellow: $y = 0.151 + 0.556x$; $y = 0.972 - 0.976x$; $y = 0.235 + 0.300x$:

| Point | Yellow | |
|---|---|---|
| | *X* | *Y* |
| 1 | 0.545 | 0.454 |
| 2 | 0.536 | 0.449 |
| 3 | 0.578 | 0.408 |
| 4 | 0.588 | 0.411 |

Green: $y = 0.655 - 0.831x$ $x = 0.150$; $y = 0.422 - 0.278x$:

| Point | Green | |
|---|---|---|
| | *X* | *Y* |
| 1 | 0.005 | 0.651 |
| 2 | 0.150 | 0.531 |
| 3 | 0.150 | 0.380 |
| 4 | 0.022 | 0.416 |

2. Color uniformity: The dominant wavelength for any individual color measurement of a portion of the emitting surface of a module shall be within ±3nm of the dominant wavelength for the average color measurement of the emitting surface as a whole.

## 2.04 ELECTRIC

All wiring and terminal blocks shall meet the requirements. Two secured, color coded, 600V, jacketed wires, a minimum of 20 AWG and at least 1 meter (39 in) in length, conforming to the NFPA 70, National Electrical Code, and rated for service at +105°C, shall be provided.

A. VOLTAGE RANGE

1. LED signal modules shall operate from a 60±3 Hz AC line power over a voltage range from 80 to 135 VAC RMS.

2. Fluctuations in line voltage over the range of 80 to 135 VAC shall not affect luminous intensity by more than ±10 percent.

3. The module circuitry shall prevent flicker of the LED output at frequencies less than 100 Hz over the voltage range specified in Section 2.04-A-1.

4. Low Voltage Turn OFF: There shall be no visible illumination from the LED signal module when the applied voltage is less than 35 VAC.

5. Turn-ON and Turn-OFF Time: A module shall reach 90% of full illumination (turn-ON) within 75 msec of the application of the nominal operating voltage. The signal shall cease emitting visible illumination (turn-OFF) within 75 msec of the removal of the nominal operating voltage.

B. TRANSIENT VOLTAGE PROTECTION

1. The on-board circuitry of a module shall include voltage surge protection, to withstand high-repetition noise transients and low-repetition high-energy transients.

C. INPUT PROTECTION (optional)

1. At the point of entry to the module for each input provide two 0.5-Ohm, 10-watt wire-wound power resistors with 0.2 micro Henries inductance (one on the AC+ Line & on the AC- Line). Provide one 20 Joule surge arrestor between AC+ to AC-. A 0.68 microfarad capacitor must be placed between AC+ & AC – (between the resistor & arrestor).

D. ELECTRONIC NOISE

1. The LED signal and associated on-board circuitry shall meet the requirements of the Federal Communication Commission (FCC) Title 47, Subpart B, Section 15 regulations concerning the emission of electronic noise by Class A digital devices.

E. POWER FACTOR AND AC HARMONIES

1. Modules shall provide a power factor of 0.90 or greater when operated at nominal operating voltage, and 25°C (77°F).

2. Total harmonic distortion induced into an AC power line by a module at nominal operating voltage, and at 25°C (77°F), shall not exceed 20%.

F. CONTROLLER ASSEMBLY COMPATIBILITY

1. The current draw shall be sufficient to ensure compatibility and proper triggering and operation of load current switches and conflict monitors in signal controller units.

2. Off State Voltage Decay: When the module is switched from the On state to the Off state the terminal voltage shall decay to a value less than 10 VAC RMS in less than 100 milliseconds when driven by a maximum allowed load switch leakage current of 10 milliamps peak (7.1 milliamps AC).

G. FAILED STATE IMPEDANCE

1. The module shall be designed to detect catastrophic loss of the LED load. Upon sensing the loss of the LED load, the module shall present a resistance of at least 250 kΩ across the input power leads within 300 msec. The LED light source will

be said to have failed catastrophically if it fails to show any visible illumination when energized according to Section 2.04-A-1 after 75 msec.

PART 3 EXECUTION

3.01 PHYSICAL & MECHANICAL REQUIREMENTS

A. GENERAL

1. Modules shall fit into existing traffic signal housings built to the VTCSH Standard without modification to the housing, or shall be stand-alone units that incorporate a housing meeting the performance and design requirements of the VTCSH Standard.

2. Installation of a module into an existing signal housing shall not require the use of special tools. The module shall connect directly to existing electrical wiring system.

3.02 CONSTRUCTION

A. A module shall be a self-contained device, not requiring on-site assembly for installation into an existing traffic signal housing. The power supply for the module may be either integral or packaged as a separate component. The power supply may be designed to fit and mount inside the traffic signal housing adjacent to the LED signal module.

B. Assembly and manufacturing processes for a module shall be designed to assure all internal LED and electronic components are adequately supported to withstand mechanical shock and vibration due to high winds and other sources.

3.03 QUALITY ASSURANCE

A. GENERAL

1. Quality Assurance Program: Modules shall be manufactured in accordance with a vendor quality assurance (QA) program. The QA program shall include two types of quality assurance: (1) design quality assurance and (2) production quality assurance. The production quality assurance shall include statistically controlled routine tests to ensure minimum performance levels of modules built to meet this specification.

2. Record Keeping: QA process and test results documentation shall be kept on file for a minimum period of seven years.

3. Conformance: Module designs not satisfying design qualification testing and the 3.03-D shall not be labeled, advertised, or sold as conforming to this specification.

production quality assurance testing performance requirements in Sections 3.03-C and 3.03-D.

B. MANUFACTURER'S SERIAL NUMBERS

1. Each module shall be identified with the information specified in Section 2.02-A.

C. PRODUCTION TESTS & INSPECTIONS

1. Production Test Requirements: All modules tendered for sale shall undergo the following Production Testing & Inspection prior to shipment. Failure of a module to meet the requirements of Production Testing & Inspection shall be a cause for rejection. Test results shall be maintained as per requirement of Section 3.03-A-2

2. All Production Tests shall be performed at an ambient temperature of 25°C (77°F) and at the nominal operating voltage of 120 VAC.

3. Luminous Intensity: All modules shall be tested for luminous intensity. A single point measurement, with a correlation to the intensity requirements of Sections 2.03-A-1 and 2.03-A-7 may be used. The purchaser may specify additional measurements. Failure of a module to meet the requirements for minimum maintained luminous intensity (2.03-A-1) or maximum permissible luminous intensity (2.03-A-7) shall be cause for rejection of the module.

4. Power Factor: All modules shall be tested for power factor per the requirements of Section 2.04-D-1. A commercially available power factor meter may be used to perform this measurement. Failure of a module to meet the requirements for power factor (2.04-D-1) shall be cause for rejection of the module.

5. Current Consumption Measurement: All modules shall be measured for current flow in Amperes. The measured current values shall be compared against the design current values from design qualification measurements in Section 3.03-I-1. A measured current consumption in excess of 120% of the design qualification current value for an ambient temperature of 25°C (77°F) shall be cause for rejection of the module.

6. Visual Inspection: All modules shall be visually inspected for any exterior physical damage or assembly anomalies. Careful attention shall be paid to the surface of the lens to ensure there are no scratches (abrasions), cracks, chips, discoloration, or other defects. The presence of any such defects shall be cause for rejection of the module.

7. Upon final delivery The City of Houston shall randomly select two modules of each type and deliver to the same testing laboratory used to certify eligibility of product. Said modules shall be subjected to same test procedure as pre-qualifying units with all associated cost including shipping to be born by supplier. Any quality issues resulting from these tests will result in rejection of whole shipment.

D. DESIGN QUALIFICATION TESTING

1. Design Qualification Test Requirements. Design qualification testing shall be performed on new module designs, when a major design change has been implemented on an existing design, or after every 5 years that a design is in service. Modules used in design qualification testing shall be representative of the manufacturer's proposed normal production. If modules are provided with both clear and tinted lenses, the tests for Temperature Cycling (3.03-E-2), Moisture Resistance (3.03-E-3), Luminous Intensity (3.03-F-2), Luminance Uniformity (3.03-F-10), Chromaticity (3.03-F-13), Color Uniformity (3.03-F-16), and Lens Abrasion (3.03-H) shall be conducted for all lens types. The certification of UV Stabilization (3.03-H) shall be provided for all materials used in or on the emitting lenses.

2. Test data shall be retained by the manufacturer in accordance with Section 3.03-A-2, or for 72 months following final production of a specific design, whichever is longer.

3. Six modules shall be used in Design Qualification Testing. All six modules shall be subjected to conditioning (3.03-D-5), followed by the Environmental Tests (3.03-E). Following the Environmental Tests, three modules shall undergo Photometric & Colorimetric Tests (3.03-F-1), followed by the Lens Tests (3.03-G). The remaining three modules shall undergo the Electrical Tests (3.03-I), the Controller Assembly Compatibility Tests (3.03-J), and the Failed State Impedance Test (3.03-L). Tests shall be conducted in the order described herein, unless otherwise specified. Figure 2 provides a flow chart for the Design Qualification Testing.

4. In order for a module design to be considered acceptable for marking with the label described in 2.02-C, all tested modules must comply with the acceptance/rejection criteria for the Environmental Tests (3.03-E), Photometric & Colorimetric Tests (3.03-F-1), Lens Tests (3.03-G), Electrical Tests (3.03-I), Controller Assembly Compatibility Tests (3.03-J), and the Failed State Impedance Test (3.03-L).

5. Conditioning: Modules shall be energized for a minimum of 24 hours, at 100% duty cycle, in an ambient temperature of +60°C (+140°F).

E. ENVIRONMENTAL TESTS

1. Mechanical Vibration: Mechanical vibration testing shall be performed per MIL-STD-883, Test Method 2007, using three 4 minute cycles along each x, y, and z axis, at a force of 2.5 Gs, with a frequency sweep from 2 Hz to 120 Hz.

2. Temperature Cycling: Temperature cycling shall be performed per MIL-STD-883, Test method 1010. The temperature range shall include the full ambient operating temperature range specified in 3.3.2. A minimum of 20 cycles shall be performed with a 30-minute transfer time between temperature extremes and a 30-minute

dwell time at each extreme temperature. Signals under test shall be non-operating.

3. Moisture Resistance: Moisture resistance testing shall be performed per MIL-STD-810F, Test Method 506.4, Procedure I, Rain and Blowing Rain. The test shall be conducted on stand-alone modules, without a protective housing. The rainfall rate shall be 1.7 mm/min (4 in/hr) and droplet size shall predominantly be between 0.5 mm and 4.5 mm (0.02 to 0.18 in). The modules shall be vertically oriented, such that the lens is directed towards the wind source when at a zero rotation angle. The module shall be rotated at a rate of 4 degrees per minute along the vertical axis, from an orientation of –60 to +60 degrees during the test. The duration of the test shall be 30 minutes. The modules shall be energized throughout the test. The water shall be at 25° ± 5°C (77° ± 9°F). The wind velocity shall be 80 km/hr (50 mph). If the module is equipped with a remote power supply unit, then the test shall be conducted with the remote power supply unit attached to the clamping device holding the module to the test apparatus.

4. Environmental Tests Evaluation: At the conclusion of the Environmental Tests, all the modules will be visual inspected for damage and energized to insure proper operation.

5. Acceptance/Rejection Criteria: The loosening of the lens, or any internal components, or evidence of other physical damage, such as cracking of the module lens or housing, or presence of internal moisture, or failure to operate correctly after testing shall be considered a failure of the design.

F. TESTS

1. Photometric & Colorimetric Tests: Three of the modules that were subjected to the Environmental Tests shall undergo Photometric & Colorimetric Tests. Unless otherwise specified, these tests shall be performed with the modules energized at nominal operating voltage.

2. Luminous intensity at standard temperature: The modules shall be tested for compliance with the requirements for minimum maintained luminous intensity at a temperature of 25°C (77°F). Measurements shall be made for all angular combinations specified in Table 1, or at other angles, as specified by the purchaser.

3. Luminous intensity measurements for red and green signal modules shall be made after the signal module has been operated under the test conditions for a minimum of 60 minutes at a 100% duty cycle.

4. Luminous intensity measurements for yellow signal modules shall be made after the module has been operated under the test conditions for a minimum of 60 minutes at a 12.5% duty cycle (5 seconds ON and 35 seconds OFF). Readings shall be taken at the end of the 5-second ON interval, or as close to the end of the ON interval as possible.

5. Luminous intensity at low voltage: The modules shall be tested for compliance with the requirements for minimum maintained luminous intensity when operated at 80 VAC at a temperature of 25°C (77°F). A single-point correlation measurement of the luminous intensity, in the region from 0 to 7.5 degrees down, and from 7.5 degrees left to 7.5 degrees right shall be recorded. The single-point measurement shall be correlated to the measurement made in the same direction under Section 3.03-F-2 to generate a full range of luminous intensity values at reduced voltage. The luminous intensity measurement at reduced voltage shall be made immediately following measurements for luminous intensity at standard temperature (3.03-F-2), and following the same procedures as in 3.03-F-3 and 3.03-F-4.

6. Luminous intensity at elevated voltage: The modules shall be tested for compliance with the requirements for minimum maintained luminous intensity when operated at 135 VAC at a temperature of 25°C (77°F). A single-point correlation measurement of the luminous intensity, in the region from 0 to 7.5 degrees down, and from 7.5 degrees left to 7.5 degrees right shall be recorded. The single-point measurement shall be correlated to the measurement made in the same direction under Section 3.03-F-2 to generate a full range of luminous intensity values at elevated voltage. The luminous intensity measurement at elevated voltage shall be made immediately following measurements for luminous intensity at reduced voltage (3.03-F-5) and following the same procedures as in 3.03-F-3 and 3.03-F-4.

7. Luminous intensity at high temperature: The modules shall be tested for compliance with the requirements for minimum maintained luminous intensity at a temperature of 74ºC (165ºF). The modules shall be mounted in a temperature chamber so that the lens is outside the chamber and all portions behind the lens are within the chamber at a temperature of 74ºC (165ºF). The air temperature in front of the lens shall be maintained at a minimum of 49°C (120°F) during all tests. A single-point correlation measurement of the luminous intensity, in the region from 0 to 7.5 degrees down, and from 7.5 degrees left to 7.5 degrees right shall be recorded. The single-point measurement shall be correlated to the 25°C (77°F) measurement made in the same direction under Section 3.03-F-3 to generate a full range of luminous intensity values at high temperature.

8. Luminous intensity measurements for red and green signal modules shall be made after the module has been operated under the test conditions for a minimum of 60 minutes at a 100% duty cycle.

9. Luminous intensity measurements for yellow signal modules shall be made after the module has been operated under the test conditions for a minimum of 60 minutes at a 12.5% duty cycle (5 seconds ON and 35 seconds OFF). Readings shall be taken at the end of the 5-second ON interval, or as close to the end of the ON interval as possible.

10. Luminance uniformity: The modules shall be tested for compliance with the requirements for luminance uniformity at a temperature of 25°C (77°F).

Measurements shall be made using a luminance meter located on the physical axis of the module lens at a distance such that the selected aperture samples a spot size of 25mm (1 inch) at the lens surface. The position of the luminance meter shall be translated from side to side and up and down, so as to sample the entire emitting surface of the module. The highest and lowest values of luminance shall be recorded. These measurements may be made immediately following measurements for luminous intensity at standard temperature and elevated voltage (3.03-F-6), after returning the voltage to the nominal operating voltage (120VAC).

11. Luminance uniformity measurements for the green and red signals must be made with the signal module operating at a 100% duty cycle. Therefore, it is necessary for the signal module under test to reach thermal equilibrium, and for the output to be stable prior to taking measurements.

12. Measurements for yellow signal modules shall be made after the module has been operated under the test conditions for a minimum of 60 minutes at a 12.5% duty cycle (5 seconds ON and 35 seconds OFF). Readings shall be taken at the end of the 5-second ON interval, or as close to the end of the ON interval as possible.

13. Chromaticity: The chromaticity of the emitted light from modules shall be measured at a temperature of 25°C (77°F). A spectro-radiometer with a maximum bandwidth of 4nm, or a colorimeter that has a measurement uncertainty of less than 2.5% over the emission spectra of the module, shall be used for this measurement. The spectro-radiometer or colorimeter shall be located on the physical axis of the module lens at a distance such that the selected aperture samples a spot size of 25mm (1 inch) at the lens surface. The meter shall be translated from side to side and up and down, so as to sample a minimum of nine equally distributed positions about the emitting surface of the module. The colorimetric values of the emitted light at each of the nine positions shall be recorded, and an average value calculated, based on the CIE Standard 2°Observer. These measurements may be made immediately following measurements for luminance uniformity (3.03-F-10).

14. Chromaticity measurements for the green and red signals must be made with the signal module operating at a 100% duty cycle. Therefore, it is necessary for the signal module under test to reach thermal equilibrium, and for the output to be stable prior to taking measurements.

15. Measurements for yellow signal modules shall be made after the module has been operated under the test conditions for a minimum of 60 minutes at a 12.5% duty cycle (5 seconds ON and 35 seconds OFF). Readings shall be taken at the end of the 5-second ON interval, or as close to the end of the ON interval as possible. If necessary, the ON interval may be extended to 10 seconds to permit completion of a measurement. The duty cycle between individual measurements, however, shall remain 12.5%, with a 5 second ON interval.

16. Color uniformity: The average and nine individual sets of chromaticity values of each module under evaluation shall be plotted on the CIE 1931 Chromaticity Diagram (see Figure 1).

17. Photometric & Colorimetric Tests Evaluation: At the conclusion of the Photometric & Colorimetric Tests, the measurement data shall be compared to the applicable requirements of Sections 2.03-A and 2.03-B.

18. Acceptance/Rejection Criteria: The failure of any module to meet the requirements for minimum maintained luminous intensity (2.03-A-1) or maximum permissible luminous intensity (2.03-A-7) under standard and high temperatures, the requirement for luminance uniformity (2.03-A-8) and/or the appropriate requirement for chromaticity (2.03-B) shall be considered a failure of the proposed design.

G. LENS TESTS

Following the Photometric & Colorimetric Tests, the three modules shall be subjected to the following tests of the acceptability of the lens construction.

UV Stabilization: Documentation shall be provided that certifies that the loss of direct transmission through the lens shall not cause the performance of the module to fall below the photometric requirements, or deviate from the colorimetric requirements of this specification after 60 months, or greater as specified by the manufacturer, of service in accordance with 1.03-A and 1.03-D. Documentation shall be provided for hard-coat film (if used), tinting film or material (if used) and lens material.

H. LENS ABRASION TEST

Abrasion resistance testing of the module lens shall be performed as follows:

1. A lens shall be mounted in the abrasion test fixture with the lens facing upwards.

2. An abrading pad meeting the requirements in paragraphs c) through f) below shall be cycled back and forth (1 cycle) for 12 cycles at 10cm ± 2cm per second over the whole surface of the lens.

3. The abrading pad shall be not less than 2.5cm ± 0.1cm square, constructed of 0000 steel wool and rubber, cemented to a rigid base shaped to the same contour as the lens. The "grain" of the pad shall be perpendicular to the direction of motion.

4. The abrading pad support shall be equal in size to the pad and the center of the support surface shall be within ± 2mm of parallel to the lens surface.

5. The density of the abrading pad shall be such that when the pad is mounted to its support and is resting unweighted on the lens, the base of the pad shall be no closer than 3.2mm to the lens at its closest point.

6. When mounted on its support and resting on the lens, the abrading pad shall be weighted such that a pad pressure of 14 kPa ± 1kPa exists at the center and perpendicular to the face of the lens.

7. A pivot shall be used if required to follow the contour of the lens.

8. Unused steel wool shall be used for each test.

9. Acceptance/Rejection Criteria: The photometric performance of a module following the lens abrasion test shall be 90% or more of the photometric performance of the same module measured prior to the lens abrasion test. A single point correlation as described in paragraph 3.03-F-7 may be used to determine the change in photometric performance. Failure of any module to meet the requirement for photometric performance following the lens abrasion test shall be considered a failure of the proposed design.

I. ELECTRICAL TESTS

Three of the modules that were subjected to the Environmental Tests shall undergo Electrical Tests. These tests shall be performed with the modules energized at nominal operating voltage and at a standard temperature of 25°C (77°F), unless specified otherwise.

1. Current Consumption: The current flow, in Amperes, shall be measured at various ambient temperatures across the span of the operating temperature range specified in 1.03-B. The manufacturer shall provide information (charts, tables and/or graphs) on the variation in current through 72 months of service, or greater as specified by the manufacturer, within the operating temperature range of 1.03-B. In addition, the current consumption at start-up shall be measured at 25°C (77°F) to establish the reference value used for Production Quality Assurance (3.03-C-5).

1. Low-Voltage Turn-OFF: The modules shall be connected to a variable power supply, and energized at nominal operating voltage. The applied voltage shall be reduced to

   a point where there is no visible illumination from the module when the background is at an average luminance of 0.1 cd/$m^2$ (0.01 ft-cd).

3. Turn-ON/Turn-OFF Times: Using a two-channel oscilloscope, the time delay between application of nominal operating voltage and the module reaching 90% of full light output, and the time delay between de-energizing the module and the light output dropping to 0% of full output, shall be measured.

4. Transient Voltage Immunity: The modules shall be tested for transient immunity, at minimum amplitude of 2000 volts, using the procedure described in Section 2.1.8, NEMA Standard TS 2-2003.

5. Electronic Noise: The modules shall be tested for conformance with the requirements of a Class A digital device, as specified in FCC Title 47, Subpart B, Section 15.109(b).

6. Power Factor: The power factor for the modules shall be measured and recorded. A commercially available power factor meter may be used to perform this measurement.

7. Total Harmonic Distortion (THD): The THD induced into an AC power line by the modules shall be measured and recorded. A commercially available total harmonic distortion meter may be used to perform this measurement.

8. Electrical Tests Evaluation: At the conclusion of the Electrical Tests, the measurement data shall be compared to the requirements of Sections 2.04-A through 2.04-D.

9. Acceptance/Rejection Criteria: The failure of any module to meet the requirements for low-voltage turn-OFF (2.04-A-4), turn-ON/turn-OFF times (2.04-A-5), transient voltage immunity (2.04-B), emission of electronic noise (2.04-C), minimum power factor (2.04-D-1), and/or maximum total harmonic distortion (2.04-D-2) shall be considered a failure of the proposed design.

J. CONTROLLER ASSEMBLY COMPATIBILITY TESTS

Following the Electrical Tests, three modules shall be tested for compatibility with load current switches and conflict monitors presently in service. The manufacturer shall test the design for the specific type signal control unit with which the design is intended to be compatible.

1. Load Switch Compatibility: The modules shall be tested for compatibility and proper operation with load current switches. Each module shall be connected to a variable AC voltage supply. The AC line current into the module shall be monitored for sufficient current draw to ensure proper load switch operation while the voltage is varied from 80 to 135 VAC.

2. Off State Voltage Decay Test: Each module shall be operated from a 135 VAC voltage supply. A 19.5 kΩ resistor shall be wired in series in the hot line between the module and the AC power supply. A single-pole-single-throw switch shall be wired in parallel with the 19.5 kΩ resistor. A 220 kΩ shunt resistor shall be wired between the hot line connection and the neutral line connection on the module. Conflict monitor Off state impedance compatibility shall be tested by measuring the voltage decay across the 220 kΩ shunt resistor as follows: The single-pole-single-throw switch shall be closed, bypassing the 19.5 kΩ resistor and allowing the AC power supply to energize the module. Next, the switch shall be opened and the voltage across the 220 kΩ shunt resistor shall be measured for decay to a value equal to or less than 10 VAC RMS. The test shall be repeated 10 times, with the longest decay time recorded as the final test value.

3. Controller Assembly Compatibility Tests Evaluation: At the conclusion of the Controller Assembly Compatibility Tests, the measurement data shall be compared to the requirements of Section 2.04-E.

4. Acceptance/Rejection Criteria: Failure of the module to draw sufficient current to ensure compatibility with the load current switches in the appropriate Controller

Assembly (2.04-E-1) and/or failure of the circuit voltage to decay to a value equal to or less than 10 VAC RMS within a time period equal to or less than 100 milliseconds (2.04-E-2) shall be considered a failure of the proposed design.

K. FAILED STATE IMPEDANCE TEST

The modules shall be tested for compliance with the requirement for provision of failed-state impedance (2.04-F). The test is conducted in two parts: first the module is energized with the LED load disconnected from the power supply to establish the failed-state impedance. Next, the requirement for the failed state impedance is tested. The module shall be operated from a 120 VAC voltage supply.

1. Wire a 50 kΩ resistor in series with the hot line between the module and the AC power supply. A 100 kΩ shunt resistor shall be wired between the hot line connection and the neutral line connection on the module. A single-pole-single-throw switch shall be wired in parallel with the 50 kΩ resistor. With the switch in the closed position and the LED load disconnected from the module power supply, energize the module for 300ms to establish the failed state impedance (5.7.2).

2. The second part of the failed state impedance test is conducted to insure that the appropriate failed state impedance is established. The switch is opened and the circuit is energized by the 120VAC voltage supply. The voltage across the 100 kΩ shunt resistor shall be continuously monitored. The voltage shall decay to a value equal to or greater than 70 VAC RMS. For the continuous interval of 500 ms through 1500 ms, after energizing the circuit with an open switch, the measured voltage shall be 70 VAC RMS or greater. The second part of the test shall be repeated 10 times, with the minimum voltage recorded during the continuous interval of 500 ms through 1500 ms, after energizing the circuit with an open switch, recorded as the final test value.

3. Failed State Impedance Test Evaluation: At the conclusion of the Failed State Impedance Test, the measurement data shall be compared to the requirement of Section 2.04-F.

4. Acceptance/Rejection Criteria: Failure of the voltage across the 100 kΩ shunt resistor to remain at a value equal to or greater than 70 VAC RMS for the continuous time interval of 500 ms through 1500 ms, after energizing the circuit with an open switch, shall be considered a failure of the proposed design.

END OF SECTION

## Table 1

Table 1 provides the minimum maintained luminous intensity values for the Section 16718 COH SPEC. LED Circular Signal, for the range from 12.5 degrees above to 22.5 degrees below the horizontal plane, and from 27.5 degrees left to 27.5 degrees right of the vertical plane, at 5 degree increments.

Minimum Maintained Luminous Intensity Values—Section 16718 COH SPEC LED Circular Signal

| Vertical Angle | Horizontal Angle | Luminous Intensity (candela) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 200m (8-inch) | | | 300 mm (12-inch) | | |
| | | Red | Yellow | Green | Red | Yellow | Green |
| +12.5 | 2.5 | 17 | 41 | 22 | 37 | 91 | 48 |
| | 7.5 | 13 | 33 | 17 | 29 | 73 | 38 |
| +7.5 | 2.5 | 31 | 78 | 41 | 69 | 173 | 90 |
| | 7.5 | 25 | 62 | 32 | 55 | 137 | 71 |
| | 12.5 | 18 | 45 | 24 | 40 | 100 | 52 |
| +2.5 | 2.5 | 68 | 168 | 88 | 150 | 373 | 195 |
| | 7.5 | 56 | 139 | 73 | 124 | 309 | 162 |
| | 12.5 | 38 | 94 | 49 | 84 | 209 | 109 |
| | 17.5 | 21 | 53 | 28 | 47 | 118 | 62 |
| | 22.5 | 12 | 29 | 15 | 26 | 64 | 33 |
| -2.5 | 2.5 | 162 | 402 | 211 | 358 | 892 | 466 |
| | 7.5 | 132 | 328 | 172 | 292 | 728 | 380 |
| | 12.5 | 91 | 226 | 118 | 201 | 501 | 261 |
| | 17.5 | 53 | 131 | 69 | 117 | 291 | 152 |
| | 22.5 | 28 | 70 | 37 | 62 | 155 | 81 |
| | 27.5 | 15 | 37 | 19 | 33 | 82 | 43 |
| -7.5 | 2.5 | 127 | 316 | 166 | 281 | 701 | 366 |
| | 7.5 | 106 | 262 | 138 | 234 | 582 | 304 |
| | 12.5 | 71 | 176 | 92 | 157 | 391 | 204 |
| | 17.5 | 41 | 103 | 54 | 91 | 228 | 119 |
| | 22.5 | 21 | 53 | 28 | 47 | 118 | 62 |
| | 27.5 | 12 | 29 | 15 | 26 | 64 | 33 |
| -12.5 | 2.5 | 50 | 123 | 65 | 110 | 273 | 143 |
| | 7.5 | 40 | 98 | 52 | 88 | 218 | 114 |
| | 12.5 | 28 | 70 | 37 | 62 | 155 | 81 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 17.5 | 17 | 41 | 22 | 37 | 91 | 48 |
| | 22.5 | 8 | 21 | 11 | 18 | 46 | 24 |
| | 27.5 | 5 | 12 | 6 | 11 | 27 | 14 |
| -17.5 | 2.5 | 23 | 57 | 30 | 51 | 127 | 67 |
| | 7.5 | 18 | 45 | 24 | 40 | 100 | 52 |
| | 12.5 | 13 | 33 | 17 | 29 | 73 | 38 |
| | 17.5 | 7 | 16 | 9 | 15 | 36 | 19 |
| | 22.5 | 3 | 8 | 4 | 7 | 18 | 10 |
| -22.5 | 2.5 | 17 | 41 | 22 | 37 | 91 | 48 |
| | 7.5 | 13 | 33 | 17 | 29 | 73 | 38 |
| | 12.5 | 10 | 25 | 13 | 22 | 55 | 29 |
| | 17.5 | 5 | 12 | 6 | 11 | 27 | 14 |
| -27.5 | 2.5 | 12 | 29 | 15 | 26 | 64 | 33 |
| | 7.5 | 8 | 21 | 11 | 18 | 46 | 24 |

Note 1: Luminous intensity values for equivalent left and right horizontal angles are the same.
Note 2: Tabulated values of luminous intensity are rounded to the nearest whole value.

## Table 2

Table 2 provides the minimum maintained luminous intensity values for the Section 16718 COH SPEC LED Circular Signal, for the range from 12.5 degrees above to 22.5 degrees below the horizontal plane, and from 27.5 degrees left to 27.5 degrees right of the vertical plane, at 2.5 degree increments.

Minimum Maintained Luminous Intensity Values—Section 16718 COH SPEC LED Circular Signal

| Vertical Angle | Horizontal Angle | Luminous Intensity (candela) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 200m (8-inch) | | | 300 mm (12-inch) | | |
| | | Red | Yellow | Green | Red | Yellow | Green |
| +12.5 | 0 | 18 | 45 | 24 | 40 | 100 | 52 |
| | 2.5 | 17 | 41 | 22 | 37 | 91 | 48 |
| | 5 | 17 | 41 | 22 | 37 | 91 | 48 |
| | 7.5 | 13 | 33 | 17 | 29 | 73 | 38 |
| +10.0 | 0 | 23 | 57 | 30 | 51 | 127 | 67 |
| | 2.5 | 23 | 57 | 30 | 51 | 127 | 67 |
| | 5 | 21 | 53 | 28 | 47 | 118 | 62 |
| | 7.5 | 18 | 45 | 24 | 40 | 100 | 52 |
| +7.5 | 0 | 31 | 78 | 41 | 69 | 173 | 90 |
| | 2.5 | 31 | 78 | 41 | 69 | 173 | 90 |
| | 5 | 28 | 70 | 37 | 62 | 155 | 81 |
| | 7.5 | 25 | 62 | 32 | 55 | 137 | 71 |
| | 10 | 21 | 53 | 28 | 47 | 118 | 62 |
| | 12.5 | 18 | 45 | 24 | 40 | 100 | 52 |
| +5.0 | 0 | 46 | 115 | 60 | 102 | 255 | 133 |
| | 2.5 | 45 | 111 | 58 | 99 | 246 | 128 |
| | 5 | 41 | 103 | 54 | 91 | 228 | 119 |
| | 7.5 | 36 | 90 | 47 | 80 | 200 | 105 |
| | 10 | 31 | 78 | 41 | 69 | 173 | 90 |
| | 12.5 | 25 | 62 | 32 | 55 | 137 | 71 |
| +2.5 | 0 | 69 | 172 | 90 | 153 | 382 | 200 |
| | 2.5 | 68 | 168 | 88 | 150 | 373 | 195 |
| | 5 | 63 | 156 | 82 | 139 | 346 | 181 |
| | 7.5 | 56 | 139 | 73 | 124 | 309 | 162 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 10 | 46 | 115 | 60 | 102 | 255 | 133 |
| | 12.5 | 38 | 94 | 49 | 84 | 209 | 109 |
| | 15 | 30 | 74 | 39 | 66 | 164 | 86 |
| | 17.5 | 21 | 53 | 28 | 47 | 118 | 62 |
| | 20 | 17 | 41 | 22 | 37 | 91 | 48 |
| | 22.5 | 12 | 29 | 15 | 26 | 64 | 33 |
| 0.0 | 0 | 106 | 262 | 138 | 234 | 582 | 304 |
| | 2.5 | 102 | 254 | 133 | 226 | 564 | 295 |
| | 5 | 96 | 238 | 125 | 212 | 528 | 276 |
| | 7.5 | 84 | 209 | 110 | 186 | 464 | 242 |
| | 10 | 71 | 176 | 92 | 157 | 391 | 204 |
| | 12.5 | 58 | 144 | 75 | 128 | 319 | 166 |
| | 15 | 45 | 111 | 58 | 99 | 246 | 128 |
| | 17.5 | 33 | 82 | 43 | 73 | 182 | 95 |
| | 20 | 25 | 62 | 32 | 55 | 137 | 71 |
| | 22.5 | 18 | 45 | 24 | 40 | 100 | 52 |

## Table 2 (cont'd)

| Vertical Angle | Horizontal Angle | Luminous Intensity (candela) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 200m (8-inch) | | | 300 mm (12-inch) | | |
| | | Red | Yellow | Green | Red | Yellow | Green |
| -2.5 | 0 | 165 | 410 | 215 | 365 | 910 | 475 |
| | 2.5 | 162 | 402 | 211 | 358 | 892 | 466 |
| | 5 | 150 | 373 | 196 | 332 | 828 | 432 |
| | 7.5 | 132 | 328 | 172 | 292 | 728 | 380 |
| | 10 | 112 | 279 | 146 | 248 | 619 | 323 |
| | 12.5 | 91 | 226 | 118 | 201 | 501 | 261 |
| | 15 | 71 | 176 | 92 | 157 | 391 | 204 |
| | 17.5 | 53 | 131 | 69 | 117 | 291 | 152 |
| | 20 | 38 | 94 | 49 | 84 | 209 | 109 |
| | 22.5 | 28 | 70 | 37 | 62 | 155 | 81 |
| | 25 | 20 | 49 | 26 | 44 | 109 | 57 |
| | 27.5 | 15 | 37 | 19 | 33 | 82 | 43 |
| -5.0 | 0 | 157 | 390 | 204 | 347 | 865 | 451 |
| | 2.5 | 153 | 381 | 200 | 339 | 846 | 442 |
| | 5 | 142 | 353 | 185 | 314 | 783 | 409 |
| | 7.5 | 125 | 312 | 163 | 277 | 692 | 361 |
| | 10 | 107 | 267 | 140 | 237 | 592 | 309 |
| | 12.5 | 86 | 213 | 112 | 190 | 473 | 247 |
| | 15 | 66 | 164 | 86 | 146 | 364 | 190 |
| | 17.5 | 50 | 123 | 65 | 110 | 273 | 143 |
| | 20 | 36 | 90 | 47 | 80 | 200 | 105 |
| | 22.5 | 26 | 66 | 34 | 58 | 146 | 76 |
| | 25 | 20 | 49 | 26 | 44 | 109 | 57 |
| | 27.5 | 15 | 37 | 19 | 33 | 82 | 43 |
| -7.5 | 0 | 130 | 324 | 170 | 288 | 719 | 375 |
| | 2.5 | 127 | 316 | 166 | 281 | 701 | 366 |
| | 5 | 119 | 295 | 155 | 263 | 655 | 342 |
| | 7.5 | 106 | 262 | 138 | 234 | 582 | 304 |
| | 10 | 89 | 221 | 116 | 197 | 491 | 257 |
| | 12.5 | 71 | 176 | 92 | 157 | 391 | 204 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 15 | 56 | 139 | 73 | 124 | 309 | 162 |
| | 17.5 | 41 | 103 | 54 | 91 | 228 | 119 |
| | 20 | 30 | 74 | 39 | 66 | 164 | 86 |
| | 22.5 | 21 | 53 | 28 | 47 | 118 | 62 |
| | 25 | 17 | 41 | 22 | 37 | 91 | 48 |
| | 27.5 | 12 | 29 | 15 | 26 | 64 | 33 |
| -10.0 | 0 | 89 | 221 | 116 | 197 | 491 | 257 |
| | 2.5 | 86 | 213 | 112 | 190 | 473 | 247 |
| | 5 | 81 | 201 | 105 | 179 | 446 | 233 |
| | 7.5 | 71 | 176 | 92 | 157 | 391 | 204 |
| | 10 | 59 | 148 | 77 | 131 | 328 | 171 |
| | 12.5 | 48 | 119 | 62 | 106 | 264 | 138 |
| | 15 | 38 | 94 | 49 | 84 | 209 | 109 |
| | 17.5 | 28 | 70 | 37 | 62 | 155 | 81 |
| | 20 | 20 | 49 | 26 | 44 | 109 | 57 |
| | 22.5 | 15 | 37 | 19 | 33 | 82 | 43 |
| | 25 | 12 | 29 | 15 | 26 | 64 | 33 |
| | 27.5 | 8 | 21 | 11 | 18 | 46 | 24 |

**Table 2 (cont'd)**

| Vertical Angle | Horizontal Angle | Luminous Intensity (candela) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 200m (8-inch) | | | 300 mm (12-inch) | | |
| | | Red | Yellow | Green | Red | Yellow | Green |
| -12.5 | 0 | 50 | 123 | 65 | 110 | 273 | 143 |
| | 2.5 | 50 | 123 | 65 | 110 | 273 | 143 |
| | 5 | 46 | 115 | 60 | 102 | 255 | 133 |
| | 7.5 | 40 | 98 | 52 | 88 | 218 | 114 |
| | 10 | 35 | 86 | 45 | 77 | 191 | 100 |
| | 12.5 | 28 | 70 | 37 | 62 | 155 | 81 |
| | 15 | 21 | 53 | 28 | 47 | 118 | 62 |
| | 17.5 | 17 | 41 | 22 | 37 | 91 | 48 |
| | 20 | 12 | 29 | 15 | 26 | 64 | 33 |
| | 22.5 | 8 | 21 | 11 | 18 | 46 | 24 |
| | 25 | 7 | 16 | 9 | 15 | 36 | 19 |
| | 27.5 | 5 | 12 | 6 | 11 | 27 | 14 |
| -15.0 | 0 | 30 | 74 | 39 | 66 | 164 | 86 |
| | 2.5 | 30 | 74 | 39 | 66 | 164 | 86 |
| | 5 | 28 | 70 | 37 | 62 | 155 | 81 |
| | 7.5 | 25 | 62 | 32 | 55 | 137 | 71 |
| | 10 | 20 | 49 | 26 | 44 | 109 | 57 |
| | 12.5 | 17 | 41 | 22 | 37 | 91 | 48 |
| | 15 | 13 | 33 | 17 | 29 | 73 | 38 |
| | 17.5 | 10 | 25 | 13 | 22 | 55 | 29 |
| | 20 | 7 | 16 | 9 | 15 | 36 | 19 |
| | 22.5 | 5 | 12 | 6 | 11 | 27 | 14 |
| -17.5 | 0 | 23 | 57 | 30 | 51 | 127 | 67 |
| | 2.5 | 23 | 57 | 30 | 51 | 127 | 67 |
| | 5 | 21 | 53 | 28 | 47 | 118 | 62 |
| | 7.5 | 18 | 45 | 24 | 40 | 100 | 52 |
| | 10 | 17 | 41 | 22 | 37 | 91 | 48 |
| | 12.5 | 13 | 33 | 17 | 29 | 73 | 38 |
| | 15 | 10 | 25 | 13 | 22 | 55 | 29 |
| | 17.5 | 7 | 16 | 9 | 15 | 36 | 19 |
| | 20 | 5 | 12 | 6 | 11 | 27 | 14 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 22.5 | 3 | 8 | 4 | 7 | 18 | 10 |
| -20.0 | 0 | 20 | 49 | 26 | 44 | 109 | 57 |
| | 2.5 | 20 | 49 | 26 | 44 | 109 | 57 |
| | 5 | 18 | 45 | 24 | 40 | 100 | 52 |
| | 7.5 | 17 | 41 | 22 | 37 | 91 | 48 |
| | 10 | 13 | 33 | 17 | 29 | 73 | 38 |
| | 12.5 | 12 | 29 | 15 | 26 | 64 | 33 |
| | 15 | 8 | 21 | 11 | 18 | 46 | 24 |
| | 17.5 | 7 | 16 | 9 | 15 | 36 | 19 |
| -22.5 | 0 | 17 | 41 | 22 | 37 | 91 | 48 |
| | 2.5 | 17 | 41 | 22 | 37 | 91 | 48 |
| | 5 | 15 | 37 | 19 | 33 | 82 | 43 |
| | 7.5 | 13 | 33 | 17 | 29 | 73 | 38 |
| | 10 | 12 | 29 | 15 | 26 | 64 | 33 |
| | 12.5 | 10 | 25 | 13 | 22 | 55 | 29 |
| | 15 | 7 | 16 | 9 | 15 | 36 | 19 |
| | 17.5 | 5 | 12 | 6 | 11 | 27 | 14 |

**Table 2 (cont'd)**

| Vertical Angle | Horizontal Angle | Luminous Intensity (candela) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 200m (8-inch) | | | 300 mm (12-inch) | | |
| | | Red | Yellow | Green | Red | Yellow | Green |
| -25.0 | 0 | 15 | 37 | 19 | 33 | 82 | 43 |
| | 2.5 | 13 | 33 | 17 | 29 | 73 | 38 |
| | 5 | 13 | 33 | 17 | 29 | 73 | 38 |
| | 7.5 | 12 | 29 | 15 | 26 | 64 | 33 |
| -27.5 | 0 | 12 | 29 | 15 | 26 | 64 | 33 |
| | 2.5 | 12 | 29 | 15 | 26 | 64 | 33 |
| | 5 | 10 | 25 | 13 | 22 | 55 | 29 |
| | 7.5 | 8 | 21 | 11 | 18 | 46 | 24 |

Note 1: Luminous intensity values for equivalent left and right horizontal angles are the same.
Note 2: Tabulated values of luminous intensity are rounded to the nearest whole value.

**Figure 1**

**Color Regions for LED Traffic Control Signal Lights:**

Figure 1 illustrates the acceptable color regions for traffic control signal lights using LED emitters as the light source.

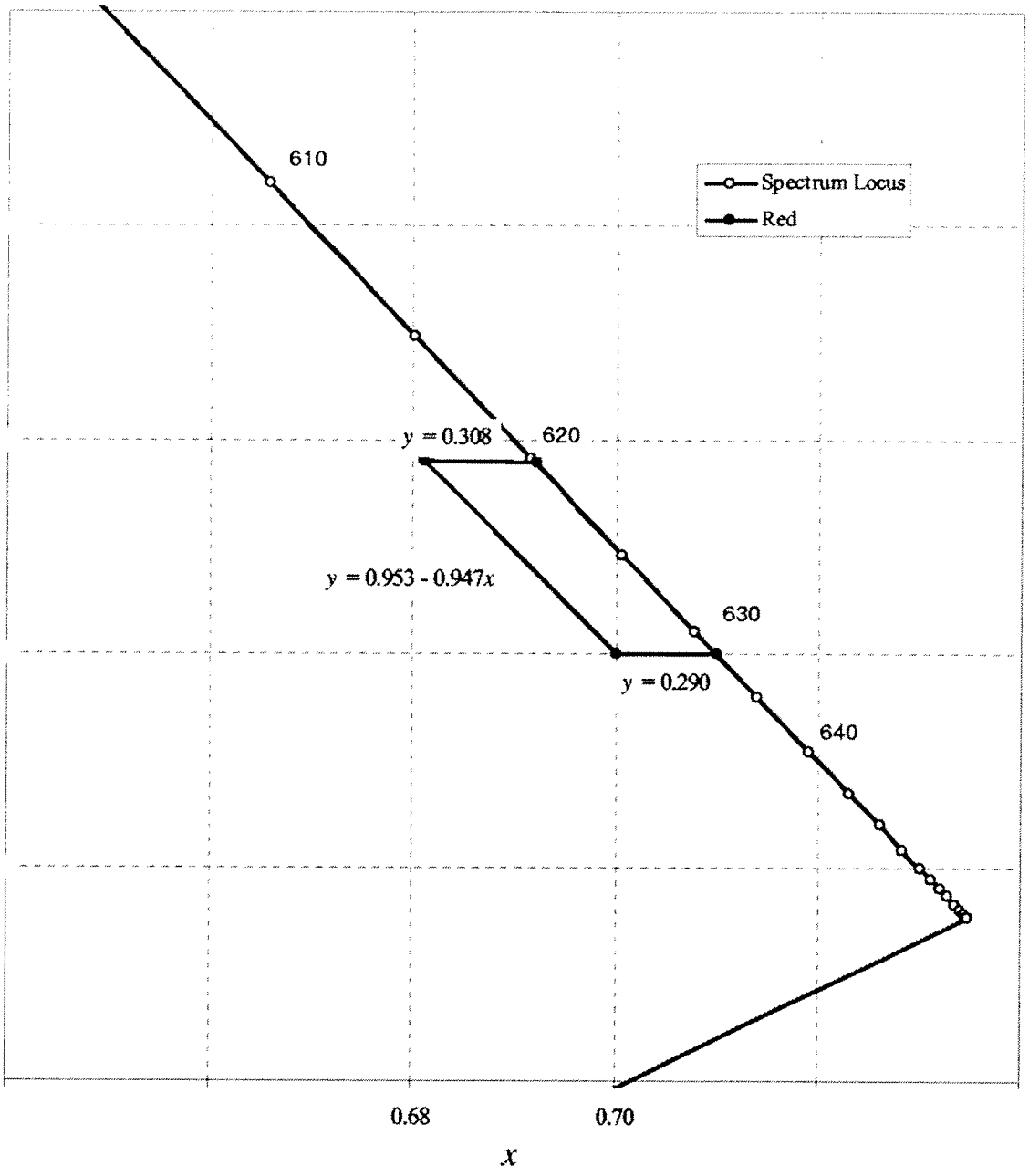



Figure 1a: Color Region for Red Traffic Control Signal Lights

**Figure 1 (cont'd)**

**Color Regions for LED Traffic Control Signal Lights:**

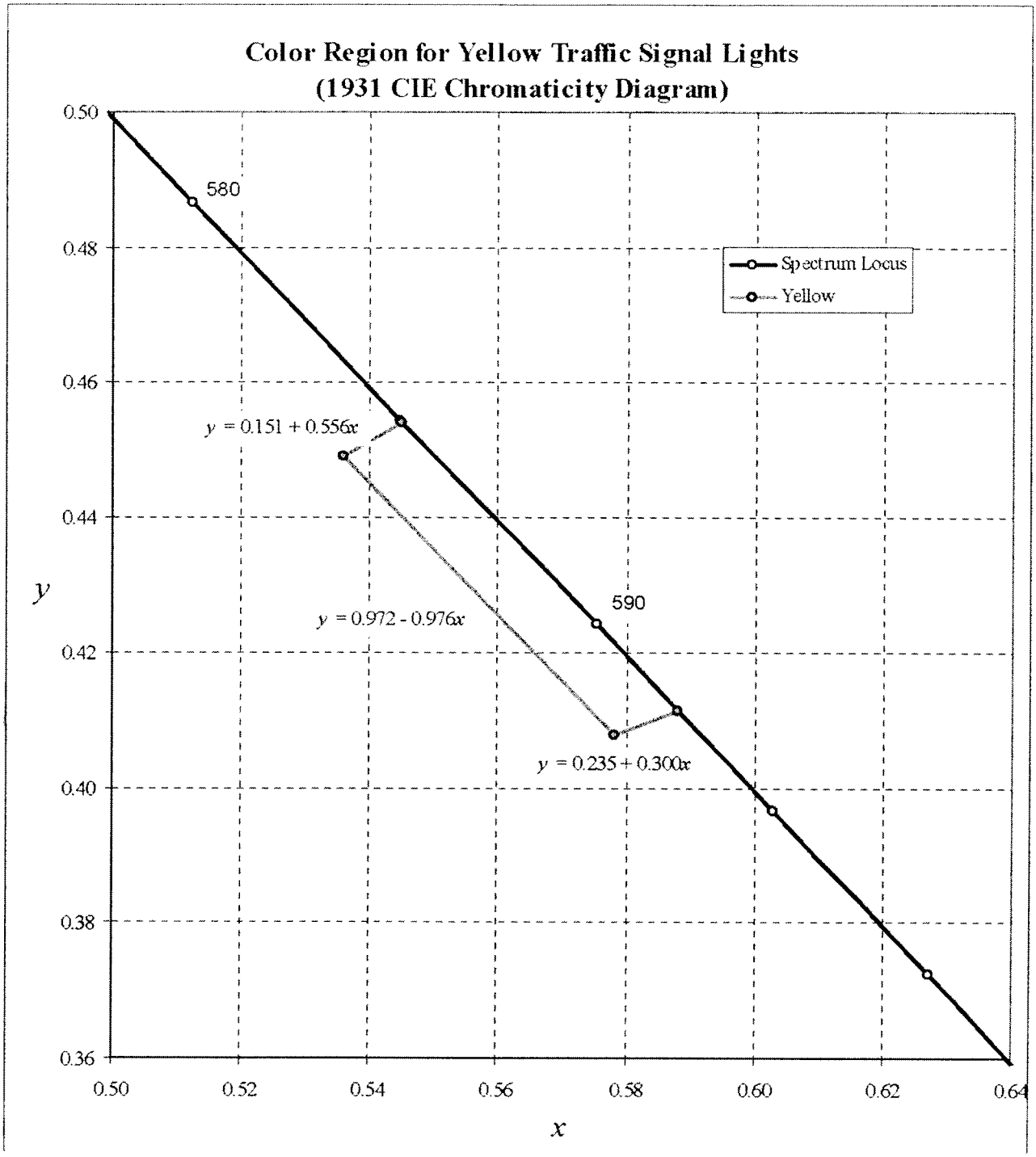
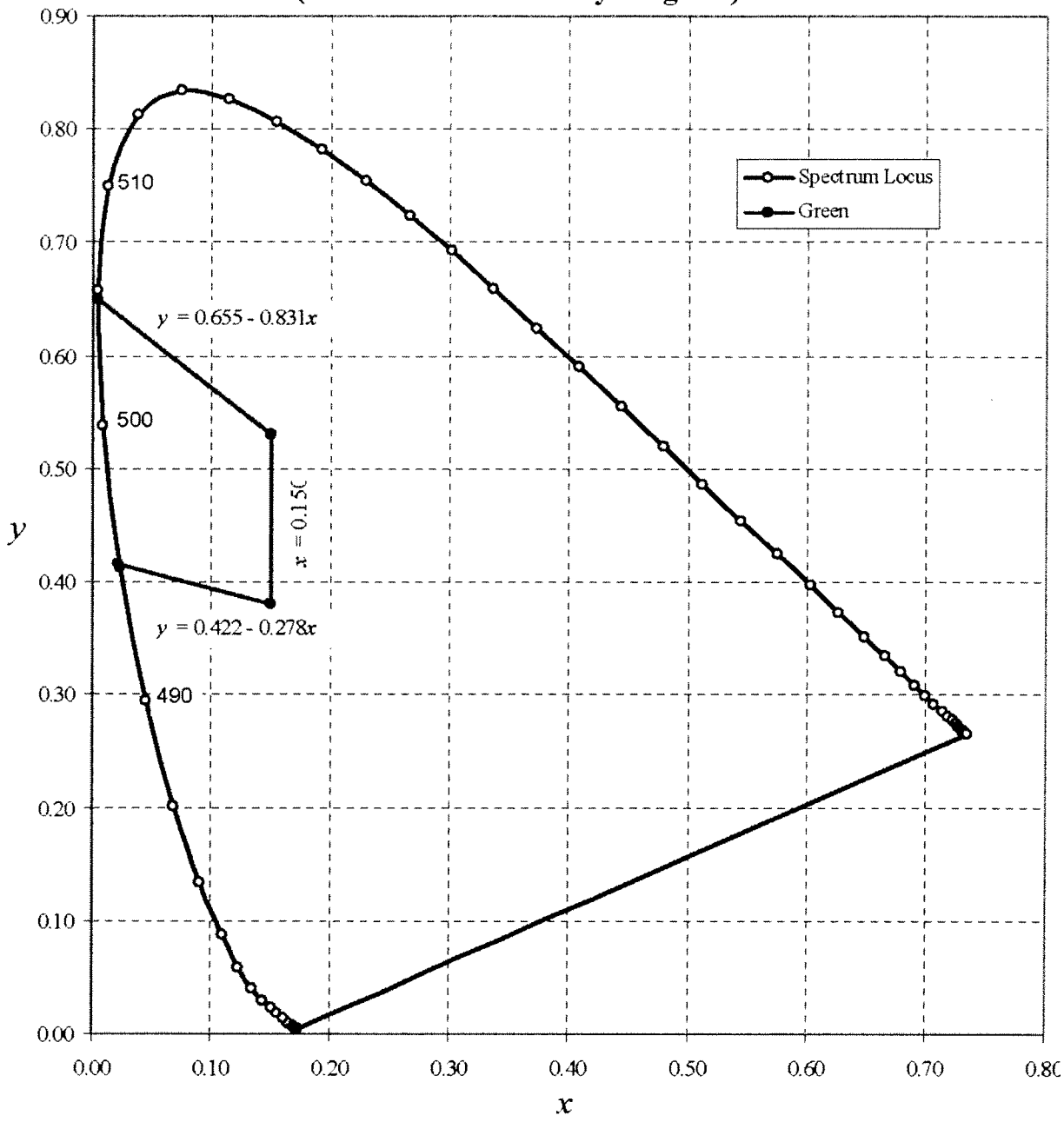



Figure 1b: Color Region for Yellow Traffic Control Signal Lights

**Figure 1 (cont'd)**

**Color Regions for LED Traffic Control Signal Lights:**

**Color Region for Green Traffic Signal Lights**
**(1931 CIE Chromaticity Diagram)**




CHECKLIST TABLES

| Article | Requirements | Comply | **Substantiation** – Explain compliance, and where required reference in Lab Reports, i.e. Page paragraph |
|---|---|---|---|
| 3.01 Physical & Mechanical Requirements – Summary | | | |
| 3.01-A-1 | Stand-alone units shall fit into VTCSH approved traffic signal housings without modification to the housing. | | |
| 3.01-A-2 | Installation of LED modules shall not require special tooling and shall connect directly to the exiting electrical wiring system. | | |
| 2.01-1 | LED module shall be capable of replacing existing optical components of the conventional signal head | | |
| 2.01-2 | The module front lens shall be compliant to the SAE J576 requirement on material exposure and weathering effects. | | Independent test lab results required |
| 2.01-3 | Lens using transparent film or material with similar color and transmissivity characteristics | | Independent test lab results required |
| 2.01-4 | The module lens may be a replaceable part, without the need to replace the complete LED signal module. | | |
| 1.03-A | All exposed components shall be suitable for prolonged exposure to the environment without interfering to the function or appearance for a period of at least 72months (in a south-facing Arizona desert) | | |
| 1.03-B | A module shall be rated for use throughout an ambient operating temperature range, measured at the exposed rear of the module, of -40°F to + 165° | | Independent test lab results required |
| 1.03-C | A module shall be protected against dust and moisture intrusion, including rain and blowing rain. (MIL-STD-810F, test method 506.4, procedure 1, Rain and Blowing Rain | | Independent test lab results required |
| 1.03-D | The module lens shall not crack, craze or yellow due to solar UV irradiation typical for a south-facing Arizona desert installation after a minimum of 72 months in service | | |
| 3.02-A | A module shall be self-contained, not requiring on-site assembly. | | |
| 3.02-B | Assembly and manufacturing processes for a module shall be designed that all internal LED and electronic components withstand mechanical shock and vibration due to high wind and other sources. (MIL-STD-883, test method 2007 | | Independent test lab results required |
| 2.01-5 | Materials used for the lens and module construction shall conform to ASTM specifications for the materials, where applicable | | |
| 2.01-6 | LED module enclosure that contains the power supply shall be made of UL94 flame retardant materials | | |
| 2.02-A | Each module shall be identified with manufacturer's name, model, operating characteristics (nominal voltage and stabilized power consumption) and serial number. | | |
| 2.02-B | Modules and removable lenses shall have a prominent and permanent vertical indexing indicator i.e. UP arrow, or the word UP or TOP for correct indexing and orientation in the signal housing. | | |

CHECKLIST TABLES (cont'd)

| Article | Requirements | Comply | **Substantiation** – Explain compliance, and where required reference in Lab Reports, i.e. Page paragraph |
|---|---|---|---|
| 2. Photometric Requirements – Summary | | | |
| 2.03-A-1 | Minimum Luminous intensity must be maintained over the temperature range of -40°F to +165°F **(for RED and GREEN) and from –40°F to +77°F (for YELLOW)** over the voltage range of 80 to 135 V AC for a minimum period of 72 months. As per ITE 3.03-F-2, 3.03-F-4, 3.03-F-5, 3.03-F-6 test methodology.<br><br>**NOTE: The test report from independent lab only represents lamp performance at day 1. Therefore to allow for inherent technology light depreciation over time and to compensate for high ambient temperature (165°F), manufacturer shall provide initial intensity values by color as follow: RED – 160%, YELLOW – 110%, GREEN – 135% at 25°C.** Refer to the attached table 1 (minimum maintained luminous intensity) | | Independent test lab results required |
| 2.03-A-2 to A-6 | Calculations of the various intensity: vertical, horizontal, peak minimum, minim maintained luminous intensity at different angles as per methodology. | | Independent test lab results required |
| 2.03-A-7 | Maximum permissible luminous intensity shall not exceed three times the required peak value of the minimum maintained luminous intensity for the selected signal size and color as methodology. | | Independent test lab results required |
| 2.03-A-8 | The uniformity of the luminance ($cd/m^2$) across the entire module lens shall not exceed a max/min ratio of 10 to 1. | | Independent test lab results required |
| 2.03-B-1 | Color regions: the measured chromaticity coordinates of modules shall conform to the following: Red: y=0.308, y=0.953-0.947x; y=0.290; Yellow: y=0.151 + 0.556, y=0.972 - 0.976x;y=0.235 + 0.300x; Green: y=0.655 -0.831x, x=0.150; y=0.422-0.278x. | | Independent test lab results required |
| 2.03-B-2 | Color Uniformity: The dominant wavelength for any individual color measurement of a portion of the emitting surface of a module shall be within + or - 3 nm of the dominant wavelength for the average color measurement of the emitting surface as a whole. | | Independent test lab results required |

## CHECKLIST TABLES (cont'd)

| Article | Requirements | Comply | **Substantiation** – Explain compliance, and where required reference in Lab Reports, i.e. Page paragraph |
|---|---|---|---|
| 2. Electrical Requirements – Summary | | | |
| 2.04 | Wire consist of two secured, color coded, 600 V, jacketed wires, a minimum length of 39", 20 AWG, 105°C rated, conforming to NFPA 70. | | |
| 2.04-A-1 | Voltage range of 80 to 135 VAC RMS, operate off a 60 Hz AC line (As per ITE 3.03-F-5, 3.03-F-6 test methodology). | | Independent test lab results required |
| 2.04-A-2 | Fluctuations over the voltage range of 80 to 135 VAC shall not affect the luminous intensity by more than + or - 10% (As per ITE 3.03-F-5, 3.03-F-6 test methodology). | | Independent test lab results required |
| 2.04-A-3 | The module shall prevent flicker of the LED output at frequencies less then 100 Hz over the voltage range of 80 to 135 V AC RMS | | |
| 2.04-A-4 | Low voltage turn OFF: there shall be no visible illumination from the LED signal module when the applied voltage is less than 35 V AC (As per ITE 3.03-I-2 test methodology). | | Independent test lab results required |
| 2.04-A-5 | Turn ON time: A module shall reach 90 % of full illumination within 75 msec of the application of the nominal operating voltage, Turn OFF time: The signal shall cease emitting visible illumination within 75 msec of the removal of the nominal operating voltage. (As per ITE 3.03-I-3 test methodology). | | Independent test lab results required |
| 2.04-B | Transient Voltage Protection: LED module shall withstand NEMA standard TS-2-2003, section 2.1.8 (As per ITE 3.03-I-4 test methodology). Increase the amplitude to 2000 V. | | Independent test lab results required |
| 2.04-C-1 | Emission of Electronic noise shall meet FCC Title 47, Subpart B, section 15 for class A digital device | | Independent test lab results required |
| 2.04-D-1 | Power Factor of .90 or greater at nominal voltage and 77°F (As per ITE 3.03-I-6 test methodology). | | Independent test lab results required |
| 2.04-D-2 | THD shall not exceed 20% @ 77°F (As per ITE 3.03-I-7 test methodology). | | |
| 2.04-E-1 | Sufficient current draw to ensure compatibility and proper triggering and operation of the load switches and conflict monitors in signal controller units. (As per ITE 3.03-J-1 test methodology). | | Independent test lab results required |
| 2.04-E-2 | Off state Voltage Decay: Voltage shall decay to less than 10 VAC RMS in less than 100 ms when switched from On to OFF state if maximum load switch leakage current is 10 MA peak. (As per ITE 3.03-J-2 test methodology). | | Independent test lab results required |
| 2.04-F-1 | Failed State Impedance: The module shall be designed to detect catastrophic loss of the LED load. Upon sensing loss of the LED load, the module shall present a resistance of at least 250 Kohms across the input power leads within 300 msec. The LED light source will be said to have failed catastrophically if it fails to show any visible illumination when energized according to Section 2.04-A-1 after 75 msec. (As per ITE 3.03-L test methodology). | | Independent test lab results required |

## Table 1 a. – Minimum Maintained Luminous Intensity

| Vertical Angle | Horizontal Angle | Red 8" | | Yellow 8" | | Green 8" | | RED 12" | | Yellow 12" | | Green 12" | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min. | 160% | Min. | 110% | Min. | 135% | Min. | 160% | Min. | 110% | Min. | 135% |
| 12.5 | 2.5 | 17 | 27 | 41 | 45 | 22 | 30 | 37 | 59 | 91 | 100 | 48 | 65 |
| | 7.5 | 13 | 21 | 33 | 36 | 17 | 23 | 29 | 46 | 73 | 80 | 38 | 51 |
| 7.5 | 2.5 | 31 | 50 | 78 | 86 | 41 | 55 | 69 | 110 | 173 | 190 | 90 | 122 |
| | 7.5 | 25 | 40 | 62 | 68 | 32 | 43 | 55 | 88 | 137 | 151 | 71 | 96 |
| | 12.5 | 18 | 29 | 45 | 50 | 24 | 32 | 40 | 64 | 100 | 110 | 52 | 70 |
| 2.5 | 2.5 | 68 | 109 | 168 | 185 | 88 | 119 | 150 | 240 | 373 | 410 | 195 | 263 |
| | 7.5 | 56 | 90 | 139 | 153 | 73 | 99 | 124 | 198 | 309 | 340 | 162 | 219 |
| | 12.5 | 38 | 61 | 94 | 103 | 49 | 66 | 84 | 134 | 209 | 230 | 109 | 147 |
| | 17.5 | 21 | 34 | 53 | 58 | 28 | 38 | 47 | 75 | 118 | 130 | 62 | 84 |
| | 22.5 | 12 | 19 | 29 | 32 | 15 | 20 | 26 | 42 | 64 | 70 | 33 | 45 |
| -2.5 | 2.5 | 162 | 259 | 402 | 442 | 211 | 285 | 358 | 573 | 892 | 981 | 466 | 629 |
| | 7.5 | 132 | 211 | 328 | 361 | 172 | 232 | 292 | 467 | 728 | 801 | 380 | 513 |
| | 12.5 | 91 | 146 | 226 | 249 | 118 | 159 | 201 | 322 | 501 | 551 | 261 | 352 |
| | 17.5 | 53 | 85 | 131 | 144 | 69 | 93 | 117 | 187 | 291 | 320 | 152 | 205 |
| | 22.5 | 28 | 45 | 70 | 77 | 37 | 50 | 62 | 99 | 155 | 171 | 81 | 109 |
| | 27.5 | 15 | 24 | 37 | 41 | 19 | 26 | 33 | 53 | 82 | 90 | 43 | 58 |
| -7.5 | 2.5 | 127 | 203 | 316 | 348 | 166 | 224 | 281 | 450 | 701 | 771 | 366 | 494 |
| | 7.5 | 106 | 170 | 262 | 288 | 138 | 186 | 234 | 374 | 582 | 640 | 304 | 410 |
| | 12.5 | 71 | 114 | 176 | 194 | 92 | 124 | 157 | 251 | 391 | 430 | 204 | 275 |
| | 17.5 | 41 | 66 | 103 | 113 | 54 | 73 | 91 | 146 | 228 | 251 | 119 | 161 |
| | 22.5 | 21 | 34 | 53 | 58 | 28 | 38 | 47 | 75 | 118 | 130 | 62 | 84 |
| | 27.5 | 12 | 19 | 29 | 32 | 15 | 20 | 26 | 42 | 64 | 70 | 33 | 45 |
| -12.5 | 2.5 | 50 | 80 | 123 | 135 | 65 | 88 | 110 | 176 | 273 | 300 | 143 | 193 |
| | 7.5 | 40 | 64 | 98 | 108 | 52 | 70 | 88 | 141 | 218 | 240 | 114 | 154 |
| | 12.5 | 28 | 45 | 70 | 77 | 37 | 50 | 62 | 99 | 155 | 171 | 81 | 109 |
| | 17.5 | 17 | 27 | 41 | 45 | 22 | 30 | 37 | 59 | 91 | 100 | 48 | 65 |
| | 22.5 | 8 | 13 | 21 | 23 | 11 | 15 | 18 | 29 | 46 | 51 | 24 | 32 |
| | 27.5 | 5 | 8 | 12 | 13 | 6 | 8 | 11 | 18 | 27 | 30 | 14 | 19 |
| -17.5 | 2.5 | 23 | 37 | 57 | 63 | 30 | 41 | 51 | 82 | 127 | 140 | 67 | 90 |
| | 7.5 | 18 | 29 | 45 | 50 | 24 | 32 | 40 | 64 | 100 | 110 | 52 | 70 |
| | 12.5 | 13 | 21 | 33 | 36 | 17 | 23 | 29 | 46 | 73 | 80 | 38 | 51 |
| | 17.5 | 7 | 11 | 16 | 18 | 9 | 12 | 15 | 24 | 36 | 40 | 19 | 26 |
| | 22.5 | 3 | 5 | 8 | 9 | 4 | 5 | 7 | 11 | 18 | 20 | 10 | 14 |
| -22.5 | 2.5 | 17 | 27 | 41 | 45 | 22 | 30 | 37 | 59 | 91 | 100 | 48 | 65 |
| | 7.5 | 13 | 21 | 33 | 36 | 17 | 23 | 29 | 46 | 73 | 80 | 38 | 51 |
| | 12.5 | 10 | 16 | 25 | 28 | 13 | 18 | 22 | 35 | 55 | 61 | 29 | 39 |
| | 17.5 | 5 | 8 | 12 | 13 | 6 | 8 | 11 | 18 | 27 | 30 | 14 | 19 |
| -27.5 | 2.5 | 12 | 19 | 29 | 32 | 15 | 20 | 26 | 42 | 64 | 70 | 33 | 45 |
| | 7.5 | 8 | 13 | 21 | 23 | 11 | 15 | 18 | 29 | 46 | 51 | 24 | 32 |